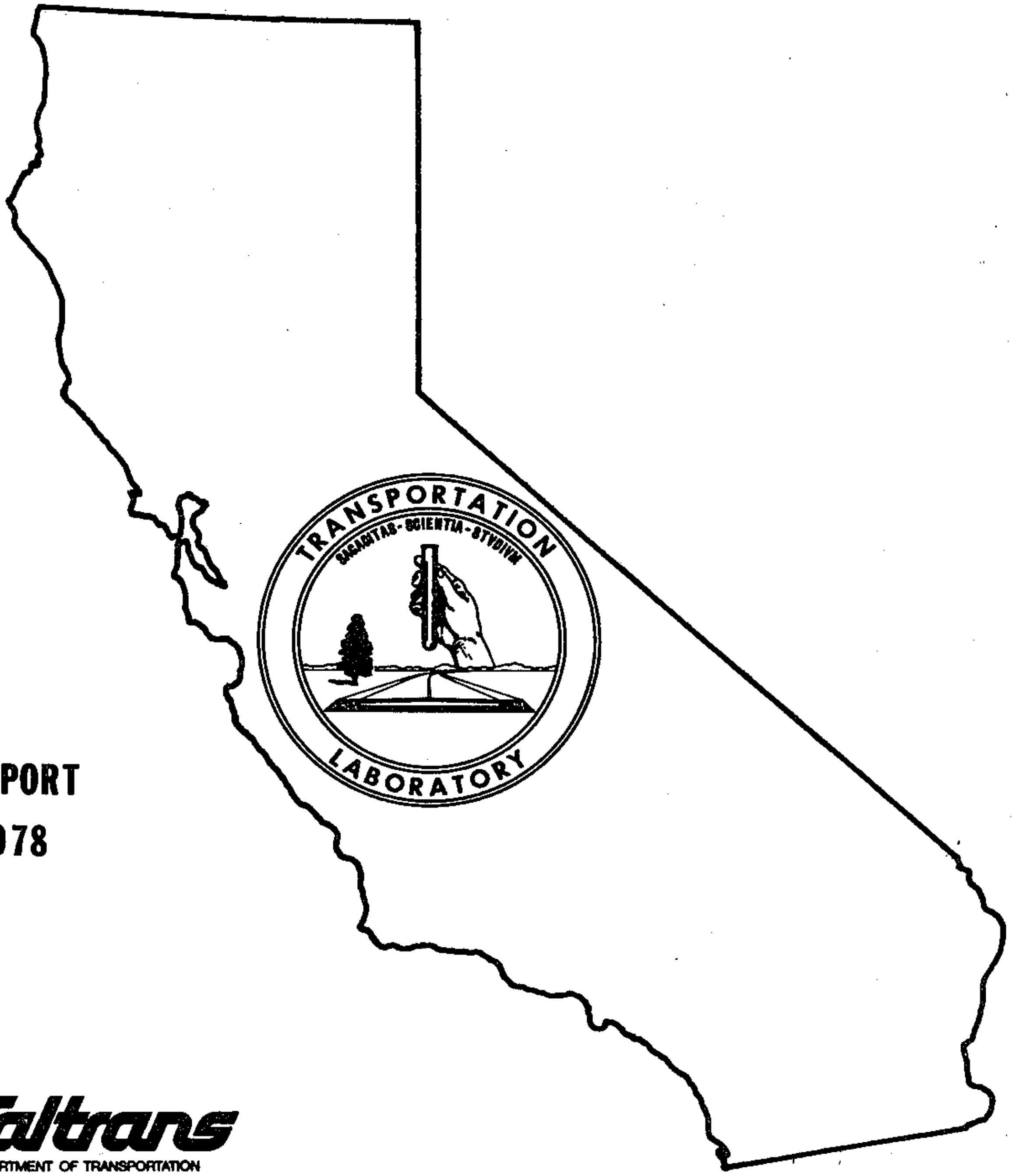
REPORT NO. FHWA-CA-TL-78-23

CALCULATING EARTHWORK FACTORS USING SEISMIC VELOCITIES



FINAL REPORT

AUG 1978

Caltrans

CALIFORNIA DEPARTMENT OF TRANSPORTATION

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16. ABSTRACT

This study was made for the purpose of developing an empirical correlation between the seismic velocity of several rock materials and their earthwork factors.

Two new curves were developed for volcanic rocks; one for hard flow rock, and one for pyroclastics.

Three highway projects constructed through sedimentary rocks were studied to determine if their earthwork factors could be correctly determined from the curve developed by a previous research study. The factors from construction on two of these projects were lower than factors estimated from the curve. The factor from the third project was higher than the curve indicated it should be. The curve was adjusted slightly to give a reasonable fit with the two projects plus the original study project. The third project was considered to represent a different material condition, and a new curve was developed that applied only to it.

A construction project through granitic rock was also studied to determine if it would yield a factor that could be correctly determined from the curve developed by the original study. The field earthwork factor from this project did agree with that predicted by the curve.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

August 1978

FHWA No. F-7-110
TL No. 632154

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research report titled:

CALCULATING EARTHWORK FACTORS
USING SEISMIC VELOCITIES

Study made by .... Geotechnical Branch

Under the Supervision of .... Raymond A. Forsyth
Marvin L. McCauley

Principal Investigator .... Elgar E. Stephens

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

EES:bjs
Attachment

FOX RIVER BOND

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Fox River Bend

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INTRODUCTION

The earthwork factor on a highway grading project is the ratio of embankment to excavation volume. A factor of 1.0 indicates no volumetric change from excavation to emplacement. Less than 1.0 indicates the material will be compacted to a denser state in the embankment than it was in the natural state before excavation. However, both excavation and embankment quantities require adjustment prior to calculation of the earthwork factor. Any imported embankment would not be considered, nor would any excavated material which is used as base, subbase, or is wasted, or exported. Criteria that affect the earthwork factor are:

1. Size of particles or pieces.
2. Degree of compaction.
3. Mixture of particle sizes in embankment.
4. Loss of material over the side of embankments.
5. Cut or fill slopes that deviate from plans.

In an earlier study by this Laboratory(1,2,3,4), the correlation of earthwork factors to the seismic velocities of a limited number of rock types at four locations in California were investigated. As a part of that study, district personnel of all state highway districts were interviewed to learn their approach to determining earthwork factors, and to assess the accuracy of such determinations. It was found that the design earthwork factor was determined by means of:

1. Materials investigation of the proposed alignment.
2. Records of past projects in assumed similar materials.
3. Experience in the area.

Such determinations resulted in design earthwork factors that varied from the actual factor by as much as 17%, with many of them in the range of 10%.

Information from the previous study has been used to determine earthwork factors on a number of projects. Because the data does not cover all rock types found in the state, additional information was needed to make possible a fuller utilization of the results of the previous investigation.

To achieve this goal, the objectives of this study were:

1. To correlate seismic velocities with earthwork factors in a variety of major rock types found throughout California.

2. To verify that the information obtained in the previous study is valid for similar rock at other locations.

CONCLUSIONS

Two new curves that show the relationship between seismic velocities and earthwork factors have been developed for volcanic rocks. One curve is to be used for hard flow rocks and the other for tuff and other pyroclastics. These curves, shown in Figure 4, can be used to compute earthwork factors when volcanic rocks are present. The predicted value should be within ±5 percent of the actual factor.

A slight modification of the previously developed curve for sedimentary rocks was made during this study. This curve, for use in computing earthwork factors for sedimentary rocks, is shown in Figure 7.

Earthwork factors developed on one construction project did not fit the sedimentary rock curve. This material apparently is overconsolidated and cannot be remolded to the in-place density easily. Therefore, an earthwork factor-seismic velocity curve (Figure 9) was developed for this particular material. This curve is tentative and should be evaluated on projects where the sediments are overconsolidated.

Construction projects in granitic rock that were considered in this study verified the curve that had been developed in our previous research. Use of the earthwork factor-seismic velocity curve for granitic rock (Figure 10) provides earthwork factors that are within ±5 percent of the actual factor.

RECOMMENDATIONS

Estimates of earthwork factors based on curves developed by this study should be applied to projects where seismic studies are conducted. The results of this application will indicate where further refinement is necessary.

More information should be developed for overconsolidated materials.

IMPLEMENTATION

The earthwork factor is used during the design stage of a facility to determine a distribution of earthwork quantities. An accurate earthwork factor will reduce unexpected increases in construction costs due to excesses or shortages of material.

The graphs developed by this study will be distributed to the various California Transportation Districts for their use in relating seismic velocities to earthwork factors.

These graphs will also be used by the Transportation Laboratory to calculate earthwork factors for the Districts at their request.

TEST PROCEDURES

The relatively small number of construction projects underway during the period of this study limited the scope of this investigation to a total of eight projects.

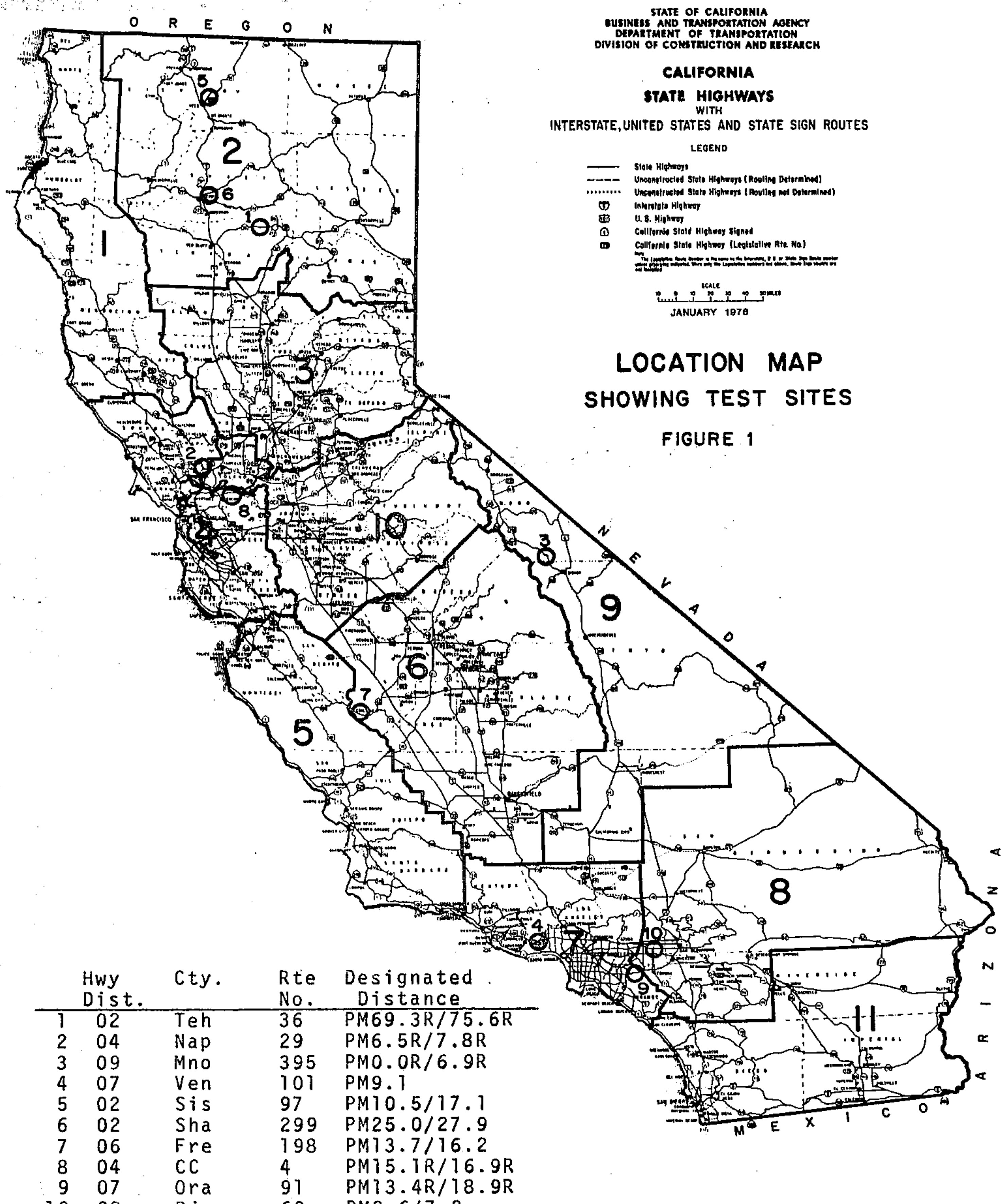
Seismic refraction velocities of the materials on each project were obtained by either running seismic refraction lines during or after construction, or by using seismic data from previous studies; and by using data obtained by consultants to the contractors. Construction activity was monitored on projects in progress during the course of the study. Resident engineers and inspectors were interviewed where possible, and most projects were photographed.

Seismic data were plotted on cross sections of the excavated areas. The total volume of excavation and the volumes of each layer of differing seismic velocity were calculated from the cross section data using the average end area method. Embankment volumes were determined, usually, by the project engineer's staff. Quantities of imported or wasted material were measured and considered in the determination of these volumes. A table was constructed for each project showing the material in each seismic velocity category, percentage of the total volume represented by that velocity, and the earthwork factor for each velocity from one of the curves. The product of the percentage volume times the factor for that velocity represents the fraction of the total earthwork factor contributed by that velocity range. The sum of these fractional parts is the estimated earthwork factor for that project using that curve.

The eight projects studied were located throughout the State and represent three different rock types. Four projects were in volcanic, three in sedimentary, and one in granitic rock. The four projects in volcanic rock represent varied kinds of volcanic material with differences in physical properties. The three sedimentary rock projects represent three different rock types at widely scattered locations.

The single granitic site represents a particular type of material not investigated during the previous study.

The projects are discussed in detail in the following section. Their locations are shown in Figure 1.



LOCATION MAP
SHOWING TEST SITES
FIGURE 1

	Hwy Dist.	Cty.	Rte No.	Designated Distance
1	02	Teh	36	PM69.3R/75.6R
2	04	Nap	29	PM6.5R/7.8R
3	09	Mno	395	PM0.0R/6.9R
4	07	Ven	101	PM9.1
5	02	Sis	97	PM10.5/17.1
6	02	Sha	299	PM25.0/27.9
7	06	Fre	198	PM13.7/16.2
8	04	CC	4	PM15.1R/16.9R
9	07	Ora	91	PM13.4R/18.9R
10	08	Riv	60	PM2.6/7.2

TEST SITES

Volcanic Rock

02-Teh-36-P.M. 69.3R/75.6R

As this project was completed before this study began, information on the excavation was obtained from the resident engineer, district materials engineer, and the contractor's superintendent.

The volcanic material ranged from clayey colluvium to relatively unweathered basalt and andesite; and from ashy pumaceous material to cemented agglomerate.

The seismic data were obtained after construction and were interpolated to cover the areas that had been previously excavated. It proved to be in good agreement with seismic data obtained from the contractor.

The earthwork factor predicted for this material by district personnel was 1.05. The amount of embankment produced by the planned excavation was about 18% less than predicted. The deficit was made up by flattening the slopes of several through cuts and using the material as embankment. The amount of material excavated and used for embankment construction was 941,487 yd^3 (715,530 m^3) of embankment and subbase. Although excavation quantities were well documented for this project, there is some doubt as to the accuracy of the embankment quantities. The actual earthwork factor for the project was between 0.9 and 0.92.

Table 1 shows the compilation of material in each velocity range and the development of an earthwork factor for this project using the curve developed for meta-igneous rock by the previous study(2). Although this curve was not developed with the intent that it would be used for volcanic rock, it was arbitrarily chosen for this purpose since a volcanic rock curve was not available. It was assumed volcanic rock was more like meta-igneous than any of the other types for which a curve had been developed.

The use of this curve did not provide reasonable factors. On this particular project, it indicated a factor of 1.1 as compared to the true 0.90 to 0.92 factor. Consequently, a new curve was developed based on the shape of the meta-igneous curve and factors determined from the data on this project. A total of eight trial curves were drawn, each of which was used to determine an earthwork factor from a table such as illustrated by Table 1.

The values from the trial curves were obtained by a curve fitting computer program. The curves were put into the computer in incremental form. The program determined the shape of each increment and printed out the exact factor at 50 fps (15 mps) intervals along the curve between the upper and lower limits established.

A factor of .94 was obtained from the eighth trial curve which was considered satisfactory pending a comparison with data from other projects.

04-Nap-29-P.M. 6.5R/7.8R

This project started at about the same time as the research study. It was not originally intended that it be included in this study because of the variety of materials involved. It was therefore not observed during construction.

TABLE 1

VOLCANIC MATERIALS FROM TEHAMA COUNTY AND THE EARTHWORK FACTORS DEVELOPED USING THE META-IGNEOUS CURVE

Velocity (fps)	Volume (yd^3)	% of Total	Factor From Curve	Factor Times % Volume
1200	26,420	.028052	.865	.024265
1250	22,887	.024301	.875	.021263
1350	25,167	.026721	.9	.024049
1500	94,770	.100626	.92	.092576
1750	30,352	.032227	.97	.031260
2000	30,092	.031951	1.00	.031951
2100	21,178	.022487	1.013	.022779
2150	65,853	.069922	1.02	.071320
2200	2,730	.002899	1.026	.002974
2300	19,993	.021228	1.039	.022056
2500	33,909	.036004	1.061	.038200
2550	10,599	.011254	1.066	.011997
2600	9,192	.009760	1.07	.010443
3000	2,243	.002382	1.108	.002639
3250	10,463	.011109	1.128	.012531
3450	69,633	.073936	1.144	.084583
3500	166,458	.176743	1.147	.202724
3850	24,376	.025882	1.17	.030282
4000	4,739	.005032	1.18	.005938
4250	5,145	.005463	1.195	.006528
4650	22,619	.024017	1.215	.029181
4700	20,014	.021251	1.217	.025862
4800	161,772	.171768	1.222	.209900
5000	23,415	.024862	1.23	.030580
5400	11,266	.011962	1.25	.014953
5800	2,585	.002745	1.266	.003475
6150	17,647	.018737	1.30	.024358
7400	5,992	.006362	1.33	.008462
Total	941,808*	.999673		1.097126
				1.10

*Includes local borrow

Note: feet/sec. (fps) x .305 = Meters/Sec (mps)

Cubic yards (yd^3) x .76 = Cubic Meters (m^3)

A prediction of the earthwork factor to be expected on this project had been made by the Transportation Laboratory, based on data developed during project design. Seismic and geologic data gathered at that time were used with the meta-igneous curve developed during the previous earthwork factor study(2). The earthwork factor thus developed and used was 1.24.

The material on the project consisted of interbedded volcanic rocks, including basalt, andesite, volcanic breccia and agglomerate, tuff, and relatively loose cinders. The material occurs in layers of from two to several tens of feet in thickness. The discrepancy between the predicted and actual earthwork factor may be due in part to a greater amount of the tuff, cinders, and breccia than had been anticipated. It also appears the meta-igneous curve from the original study does not predict an earthwork factor applicable to the volcanic rocks on this project.

The actual earthwork factor for this project was 1.07 as compared to the 1.09 from curve No. 8 of the set developed by the trial and error fitting procedure from the Tehama project. It was not possible to develop factors for individual materials since their velocities could not be separated from the whole. Table 2 shows the development of this factor, using curve No. 8 and the data from this project.

09-Mno-395-P.M. 0.0R/6.9R

This project was completed before our study began. Information on the construction activity was obtained from the resident engineer, his assistant, and an inspector. Seismic studies made by two consultants to the contractor were available for examination. Additional seismic work was done by the Transportation Laboratory after the project was complete. The combined data provided by these studies were interpolated to cover excavated areas.

The predominant materials were a welded tuff which was remarkably uniform throughout the project, a fine wind deposited sand, and granitic material which varied from in-place weathered material to glacial till. Because of its variability, the granitic section was eliminated from the study.

An earthwork factor had been assigned to each segment by the District. For the competent welded tuff between Stations 30 and 143 a factor of 1.04 was assigned as compared to an actual factor of 1.07. As a result, the profile grade was raised to reduce the excess material.

The factor used by design for the welded tuff and sand between Stations 231 and 277 was 1.07 as compared to the actual factor which was 0.94. Consequently the roadway cut was widened to provide the required additional material.

The seismic data were plotted on cross sections and volumes for each velocity were calculated. The earthwork factor developed using the original meta-igneous curve was 1.15 for the interval between Stations 30 and 143; and 1.14 for the interval between Stations 231 and 277, indicating that the original meta-igneous curve was not applicable. Because it was not possible to separate the individual velocities for direct correlation with an earthwork factor, a trial and error procedure was used on this project also. A table

TABLE 2

VOLCANIC MATERIAL FROM NAPA COUNTY AND THE EARTHWORK FACTOR DEVELOPED USING CURVE NO. 8

Line B

Velocity (fps)	Volume (yd^3)	% of Total	Factor From Curve	Factor Times % Volume
2150	201,440	.006177	.89	.005498
2500	24,800	.000759	.925	.000702
2600	1,243,344	.038069	.934	.035556
3150	1,565,036	.047918	.979	.046912
3850	114,168	.003496	1.024	.003580
3900	834,540	.025519	1.026	.026183
4000	4,649,188	.142348	1.032	.146903
4200	1,620,800	.049626	1.042	.051058
4300	87,000	.002664	1.048	.002792
4700	1,682,584	.051517	1.066	.054917
4950	2,322,192	.071106	1.077	.076581
5450	3,549,392	.108675	1.097	.119217
6150	1,641,800	.050268	1.122	.056401
6950	9,490,180	.290569	1.148	.333573
6800	133,712	.004094	1.144	.004684
7150	1,357,400	.041561	1.154	.047961
7450	584,800	.017905	1.162	.020806
8500	285,674	.008747	1.188	.010391
9200	1,272,600	.038964	1.20	.046796
	32,660,650	.999982		1.0905
				1.09

Line FL2

3300	63,600	.371712	.99	.367995
4700	107,500	.628287	1.066	.669754
	171,100	.999999		1.0377
				1.04

Line FF

3600	252,000	.229571	1.009	.231637
4950	719,100	.655097	1.077	.70554
6150	126,600	.115332	1.122	.129403
	1,097,700	1.000000		1.07

Line B	32,660,650	.962605	1.09	1.04924
Line FL2	171,100	.005043	1.04	.005245
Line FF	1,097,700	.032252	1.07	.03451
				1.09

Note: Feet/sec. (fps) x .305 = Meters/sec (mps)

Cubic yards (yd^3) x .76 = Cubic Meters (m^3)

TABLE 3

MATERIAL FROM BETWEEN STATIONS 231 AND 277, MONO COUNTY PROJECT, AND THE EARTHWORK FACTOR DEVELOPED USING CURVE NO. 8

Velocity (fps)	Volume (yd^3)	% of Total	Factor From Curve	Factor Times % Volume
1200	15,577	.199503	.746	.148829
1800	1,736	.022234	.847	.018832
2650	812	.010340	.939	.009709
2950	7,546	.096646	.964	.093167
4400	35,554	.455359	1.052	.479038
4950	9,700	.124233	1.077	.133799
5850	7,154	.091625	1.111	.101795
	78,079	.999940		.985169
				.99

TABLE 4

MATERIAL FROM BETWEEN STATIONS 30 AND 143, MONO COUNTY PROJECT, AND THE EARTHWORK FACTOR DEVELOPED USING CURVE NO. 12

Velocity (fps)	Volume (yd^3)	% of Total	Factor From Curve	Factor Times % Volume
1200	787	.003653	.807	.002948
1800	13,432	.062339	.913	.056916
2800	5,533	.025679	1.018	.026141
2950	30,810	.143006	1.03	.147296
3450	1,713	.007502	1.065	.00799
3500	103,608	.480853	1.069	.514032
3800	6,551	.030404	1.087	.033049
4400	30,672	.142351	1.119	.159291
4600	1,528	.007092	1.129	.008007
5600	20,833	.096688	1.168	.112932
	215,467	.999567		1.0686
				1.07

Note: feet/sec. (fps) x .305 = Meters/sec (mps)
Cubic yards (yd^3) x .76 = Cubic Meters (m^3)

was constructed showing the values from each of the trial curves developed as a part of this study. For the interval between Stations 231 and 277 (Table 3), a factor of .99 was obtained using curve No. 8.

None of the eight curves resulted in a good fit for the material from the interval between Stations 30 and 143. Consequently, additional trial curves were drawn and the process continued until curve No. 12 projected the actual construction factor of 1.07 (see Table 4).

07-Ven-101-P.M. 9.1

This project was partially completed when the study began. The seismic data had been obtained as part of the design study.

The material on this project consisted of hard dense basalt, hard broken basalt, relatively fresh to well weathered basaltic mudflow, and fresh to weathered tuff.

The earthwork factor predicted by the district design department was 1.04. The actual factor as reported by the resident engineer was 1.08. Because it was difficult to obtain volumes to calculate the earthwork factor, contour maps of the cut and fill areas were developed where needed to determine volumes.

The previously described trial and error procedure of fitting the volumes and velocities of the excavated material to an earthwork factor curve was also tried on this project. The factor from the original meta-igneous curve was 1.18(2). A fit was then tried using the trial curves developed for the other projects in volcanic rock covered in this report. Several of these curves gave factors in reasonably good agreement with the reported actual value. Since the material on this project was primarily a relatively hard flow rock, it was assumed that the curve for the welded tuff on the Mono County project could be used. That curve gives an earthwork factor of 1.11, which is 2.8% higher than actually obtained. Curve No. 10 gives the exact factor, but is 4.7% low for the welded tuff. All of the trial curves are shown in Figures 2 and 3. Table 5 presents supporting data for the earthwork factor development for this project using curve No. 12.

02-Sis-97-P.M. 10.5/17.1

This project was started after the study began and was observed before and during construction. Seismic velocities were obtained for most cut areas prior to the start of construction.

The material was a hard dense basalt, hard porous basalt, and a porous scoriaceous material.

Because useable records were not available from this project, it was dropped from the study.

Development of Curves for Volcanic Rock

Most of the projects in volcanic rock were completed before the study began. While it was possible to determine excavation and embankment quantities, and the seismic velocities of in situ materials, it was not possible to determine an earthwork factor for a given velocity of any of these materials. The original meta-igneous curve(2) did not give a factor reasonably close to the actual one, being consistently high for all volcanic material. An

TRIAL CURVES 1 THROUGH 8
FOR VOLCANIC ROCKS

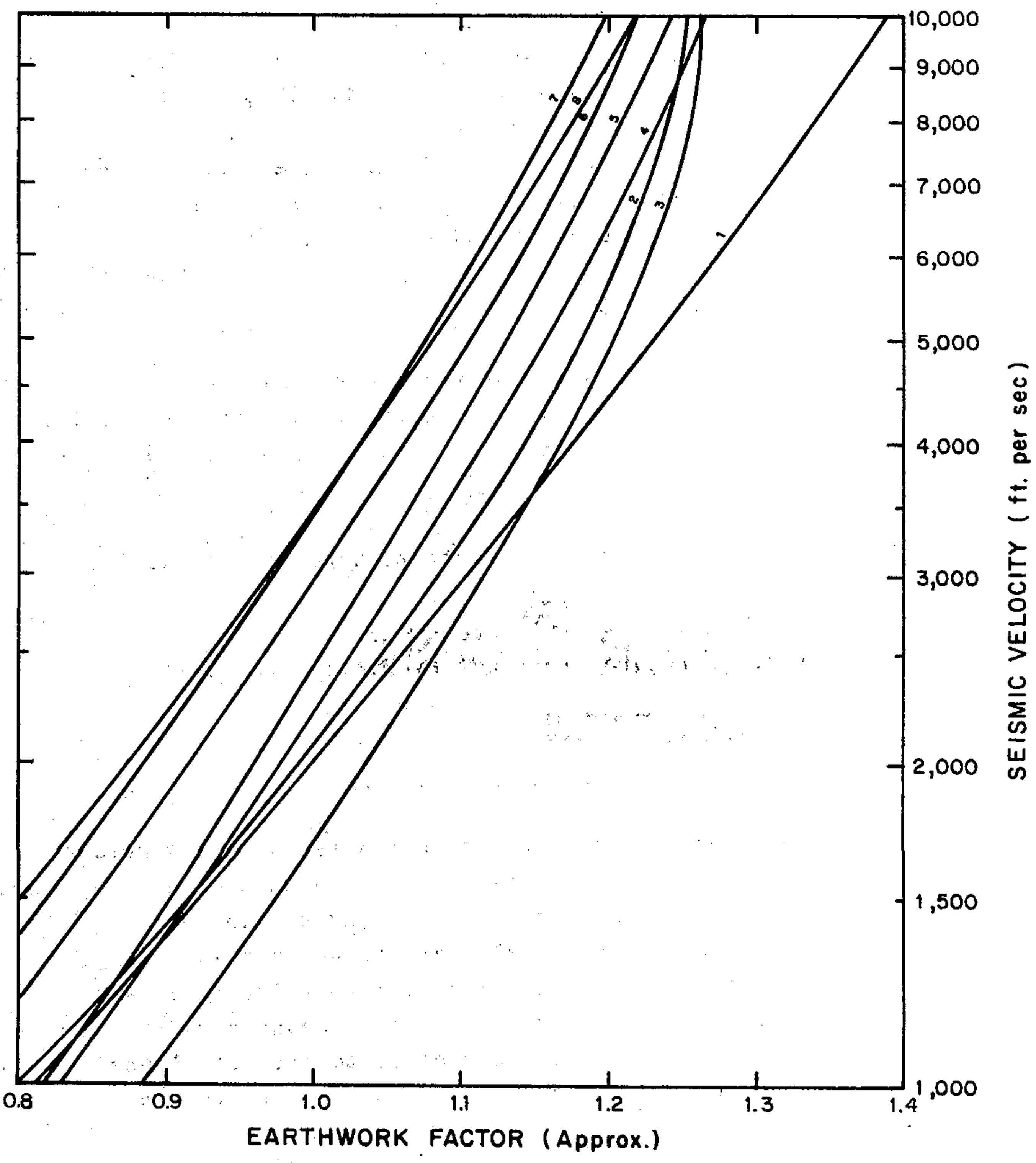


FIGURE 2

TRIAL CURVES 9 THROUGH 12 FOR VOLCANIC ROCKS

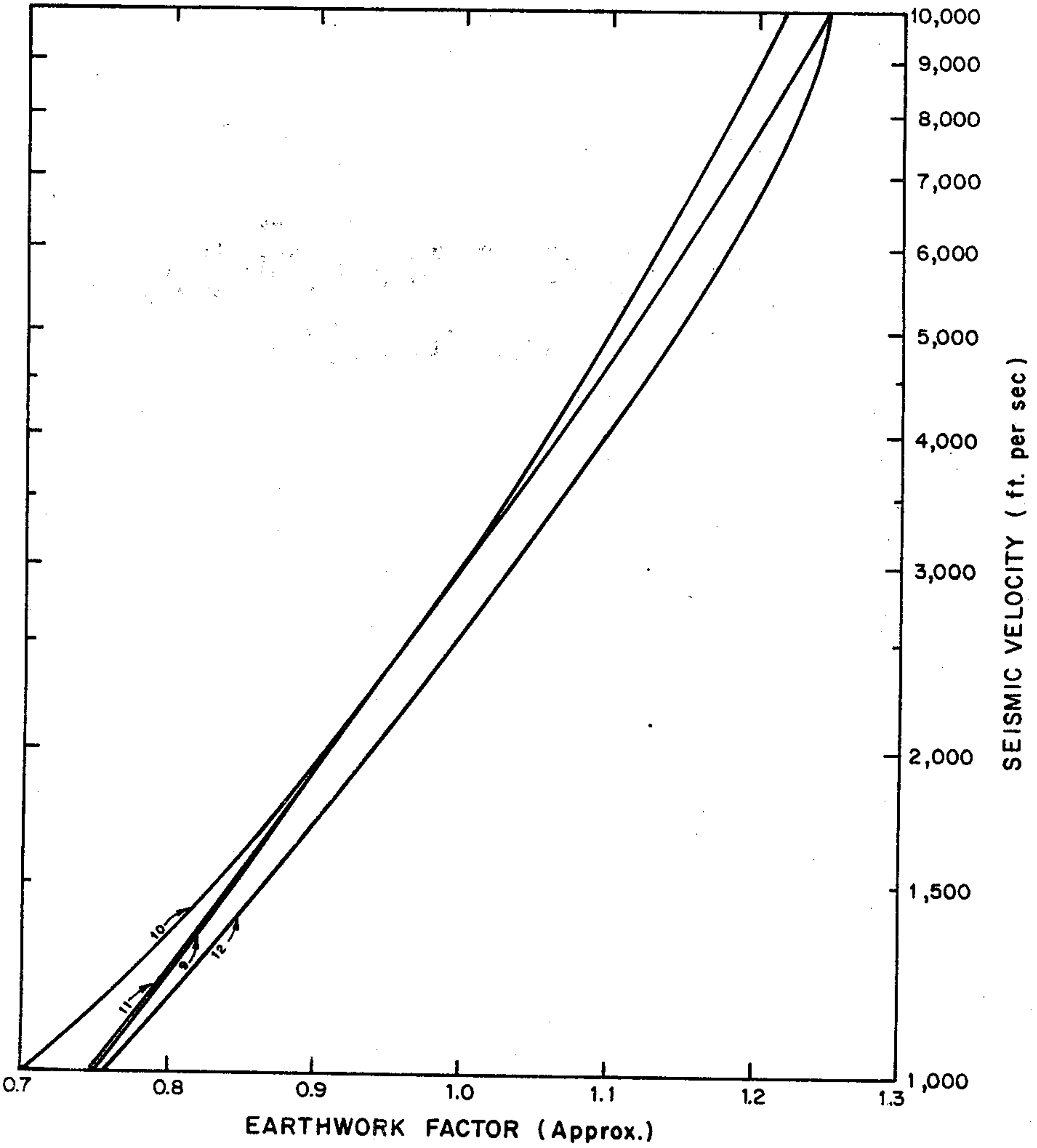


FIGURE 3

TABLE 5

VOLCANIC MATERIAL FROM THE VENTURA COUNTY PROJECT AND EARTHWORK FACTOR DEVELOPED USING CURVE NO. 12

Velocity (fps)	Volume (yd^3)	% of Total	Factor From Curve	Factor Times % Volume
1150	3,842	.012303	.796	.009793
1200	7,245	.023297	.807	.018801
1250	3,434	.010997	.818	.008996
1300	8,566	.027431	.828	.022713
1350	18,250	.058442	.838	.048974
1700	8,574	.027457	.898	.024656
1750	10,167	.032558	.906	.029498
2350	1,412	.004522	.977	.004418
2550	3,681	.011788	.996	.011741
3300	10,697	.034255	1.055	.036139
3400	834	.002671	1.062	.002837
4500	20,380	.065263	1.124	.073356
5400	72,631	.232587	1.161	.270034
5500	22,193	.071069	1.164	.082724
5550	13,904	.044525	1.166	.051916
5600	17,314	.055445	1.168	.06476?
5700	24,521	.078524	1.171	.091952
6550	13,055	.041806	1.199	.050125
6650	185	.000592	1.201	.000711
7000	18,095	.057946	1.208	.069999
7400	7,246	.023204	1.216	.028216
8400	15,275	.048915	1.233	.060214
8700	6,067	.019428	1.237	.024403
10,400	4,677	.014977	1.25	.018721
Total	312,245	1.000000		1.105697
				1.11

Note: Feet/sec. (fps) x .305 = Meters/sec (mps)

Cubic yards (yd^3) x .76 = Cubic Meters (m^3)

attempt was then made to draw a new curve, parallel to the meta-igneous, but to the left or lower earthwork factor side. For such a curve to produce the true factor, the lower seismic velocities would have had to correlate with earthwork factors as unrealistically low as 0.5. Consequently the slope of the curve was steepened and a series of curves drawn to determine a factor for each of the different projects studied.

For purposes of determining the location of points on each of these curves, certain assumptions were made about the properties of the volcanic materials. It was assumed that ashy materials would have high void ratios and would be highly compressible. It was also assumed that most low-velocity clayey materials, whether derived from hard flow rock or from ashy materials, would also be highly compressible. Hard flow rocks were considered to have a factor equal to the meta-igneous rocks.

Trial and error procedures determined that hard flow rock did not have as much swell as meta-igneous rock. Furthermore, the factor from a trial curve was greater than the actual factor when high percentages of hard flow rock were involved. The consensus opinion of resident engineers, materials engineers, and other geologists close to the work was that volcanic rocks should not have a factor greater than 1.2 to 1.3.

The process of drawing trial curves continued until two curves were produced that afforded good agreement between predicted and actual earthwork factors for volcanic materials. One curve (No. 12) fits materials that are predominantly flow rock and welded tuff while the other (No. 8) fits materials that are predominantly pyroclastics with interbedded harder rocks. The two curves, shown in Figure 4, are nearly parallel at velocities below 6000 fps (1830 mps). The curve for hard flow rock becomes much steeper above 6000 fps (1830 mps). There were no velocities higher than 7400 fps (2260 mps) for pyroclastics.

The twelve trial curves drawn using this procedure are shown an Figures 2 and 3. Each curve was put into the computer in incremental form. The program determined the shape of each increment, and printed out a listing of the precise factors for each increment of 50 fps (15 mps) velocity between the limits used. From these lists a table was plotted showing the earthwork factor for each velocity on a project as determined from each of the curves. While these two curves do not represent an exact fit for all volcanic materials, they are the best fit of the information available, and give reusltś that are within 5% of the actual factors. Further refinement may be needed as additional data are obtained.

Sedimentary Rock

02-Sha-299-P.M. 25.0/27.9

This project was completed before our study began. Information on it was obtained from the resident engineer and the district materials engineer.

The material was sedimentary, primarily well rounded gravel within a matrix of iron-stained sand and clay.

As the earthwork factor predicted by the District was 0.85, it had been planned to supplement the embankment material with 102,000 cubic yards (77,560 m^3) of imported borrow. However, the amount of import required was only 27,000 cubic yards (20,520 m^3) since the actual earthwork factor proved to be 0.95.

RELATIONSHIP BETWEEN SEISMIC VELOCITIES
AND EARTHWORK FACTORS
FOR VOLCANIC ROCK

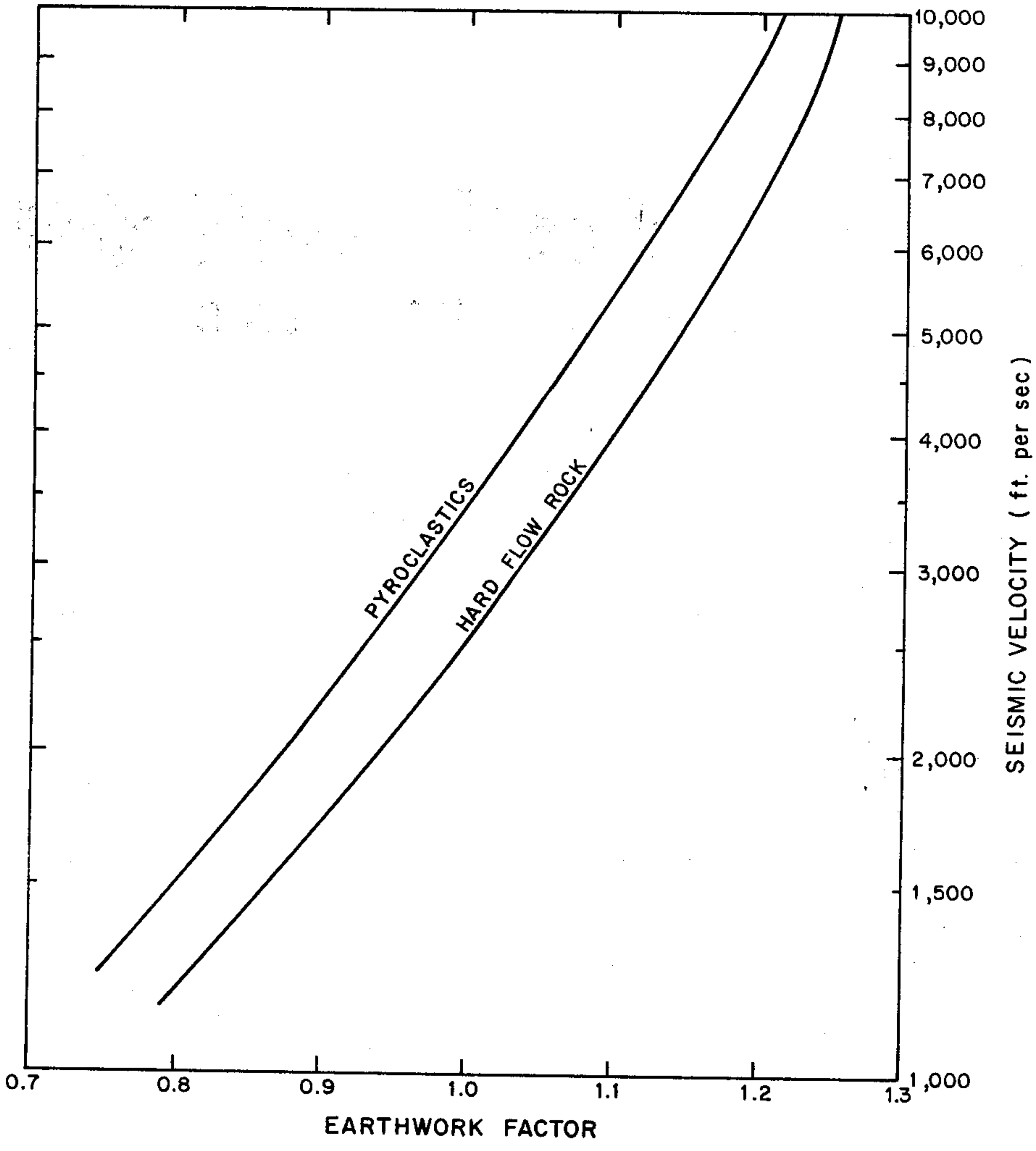


FIGURE 4

The seismic data were obtained after construction from seismic lines located along the face and top of the cut slopes. The information was then extrapolated across the areas of removed material. The volumes of material of each seismic velocity were determined and an earthwork factor developed from the curve determined during our previous research study(3). This factor was 1.02, or 7% higher than the construction factor.

06-Fre-198-P.M. 13.7/16.2

Although this project was completed before our study began, a seismic study had been conducted during the design study, prior to construction.

The excavation at this project largely involved a single cut. The material consisted of approximately five feet (1.5 m) of alluvium overlying thin-bedded shales containing occasional thin sandstone layers.

An earthwork factor of 0.80 was predicted by the District Materials Section. This factor was increased to 0.90 by the Design Department. Neither group used seismic velocities in arriving at its representive factor.

During construction it became evident that 0.90 was too low. A contract change order was written to reduce excavation and increase embankment amounts.

Using the seismic velocities from the design study and the curve developed during the previous earthwork factor research study(3) an earthwork factor of 1.00 was calculated. The actual earthwork factor was determined to be 0.95.

04-CC-4-P.M. 15.1R/16.9R

This project was observed throughout the construction period. The material was chiefly a loosely cemented clayey or silty sandstone with some harder sandstone in the lower portions of the cuts. There was considerable crosshauling and mixing of material so that isolating individual velocity material was not possible.

An earthwork factor of 1.10 had been predicted as representative of most of the material on this project. However, it became apparent early in the work that this value was too high. A seismic survey was therefore conducted to permit re-evaluation of the earthwork factor. Based on this survey and the results of the original study involving sedimentary rock(3), a factor of 1.00 was developed for the north half of the project and 0.96 for the south half. The excavation and embankment quantities were then changed by adjusting the amounts of cut and fill to conform to the new earthwork factors. Upon completion of the project, the actual earthwork factors for the north and south halves were determined to be 1.05 and 1.04, respectively. The total amount of excavation was 7,862,680 cubic yards (5,975,637 m^3).

Of the several sedimentary projects investigated for this study, this was the only one on which the actual factor was higher than predicted from the original curve(3). The loosely cemented sandstone, which had low seismic velocities and was excavated with little or no ripping was expected to have an earthwork factor of .95-1.00. After the construction factors were determined, a review of all the data was made to locate any errors that might have been made in measuring or calculating quantities. This included a review of the field factors as well as the office calculations made to relate velocities to in-place material.

There was still no explanation consistent with the available information. In situ densities were then obtained at several different depths, as well as densities of embankment material and laboratory densities of remolded material from the test sites. Moisture contents were also obtained. The in situ densities were, in most cases, higher by about 3% than the density of the remolded material. The in-place material weighed from 129 (2030 kg/m^3) to 139 (2203 kg/m^3) pounds per cubic foot, averaging about 131 (2063 kg/m^3). This was the case even for material close to the original ground surface that had a low seismic velocity. It required many blows to penetrate the in-place sandstone with a 3/4 inch steel pin in order to make a hole for the nuclear gauge probe. It was also quite difficult to dig with a shovel, although it could be readily crumbled by hand to individual grain size after excavation.

According to the geologic record, this material had been buried by later deposits and then uncovered by erosion. It is therefore, overconsolidated.

The sandstone found on this project is more dense in-place than in the remolded condition. Consequently the material swells and occupies a greater volume in the embankment than in the cut area. The 90 to 92% relative compaction achieved by the contractor was a percentage of the remolded, not of the in-place density.

07-Ora-91-P.M. 13.4R/18.9R

This project was used in the original study done during 1971(3,4). The material consisted primarily of weathered loosely cemented sandy clayey conglomerate, sandy silt, sandy gravelly clay, and clayey sandstone.

This project was included here to provide a review of the original data and to allow it to be included in the trial and error curve fitting process.

There was a small rounding of the original data that could be contributing to the factors developed from the original curve at other projects being too high. The project involved 6,843,815 cubic yards (5,201,300 m^3) of material. The actual earthwork factor was .996 which was rounded upwards to 1.00. A trial and error curve fitting process was then used to develop a best fit with the unity value.

The upward rounding was not significant, but did result in the calculated volume being 24,000 cubic yards (18,240 m^3) more than existed. Factors developed using this curve, at projects other than the one in Contra Costa County, were too high. A new curve was therefore developed using data from all sedimentary projects except the one in Contra Costa County.

Development of a Revised Curve for Some Sedimentary Rock

The sedimentary rock curve developed by our original research(1,2,3,4) predicted factors higher than the construction factors for the projects in Shasta County and in Fresno County. On the other hand it gave a predicted factor that was much too low for the Contra Costa County project. A decision was therefore made to exclude the data from the Contra Costa County project and consider it as a special case that will be described later.

An adjustment of the curve was considered necessary for the projects that were yielding a factor that was too high (see Table 6). The adjustment was accomplished by a trial and error procedure. New curves were drawn and the factor developed from each new curve was compared with the known field earthwork factor. A total of eleven trial curves were drawn, using several different slopes and shapes. The trial curves are presented by Figures 5 and 6.

After each trial curve was drawn, it was introduced into the computer in incremental form. The program determined the shape of each increment and printed out the factor at 50 fps (15 mps) intervals along the curve from 1000 fps (305 mps) to 8000 fps (2440 mps). The printouts were then used to compile a table showing the seismic velocities, volume of material within each velocity, the factor for that velocity and the sum of each of these fractional factors. The sum of the fractional factors for each velocity was the earthwork factor for that project using that particular trial curve. Each trial factor was then compared with the known factor obtained in the field. See Tables 7, 8, and 9 for data from these three projects.

This trial and error procedure was continued until a reasonable fit was achieved with the data from the three projects. Trial curve No. 11, shown in Figure 6 and by itself in Figure 7, gave the best fit. The data from the Orange County project produced the best individual fit with a 1.1% error on the low side. The curve was 3.7% too high for the Fresno County project and 5% too high for the Shasta County project. The reliability of the field data is best for the Orange County project and poorest on the Shasta County project where there was some question about the volume of embankment.

TRIAL CURVES 1 THROUGH 5
FOR SEDIMENTARY ROCKS

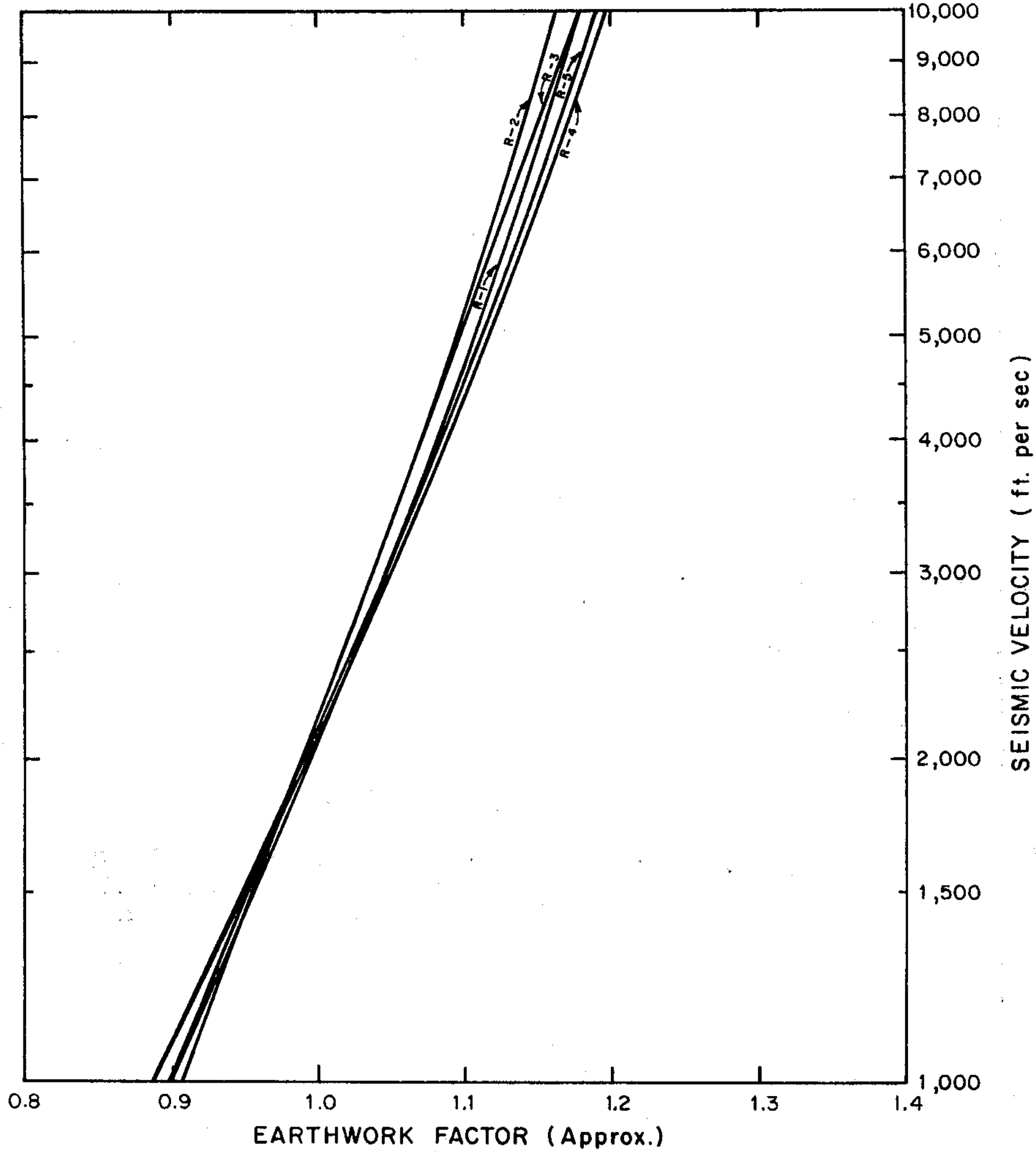


FIGURE 5

TRIAL CURVES 6 THROUGH 11
FOR SEDIMENTARY ROCKS

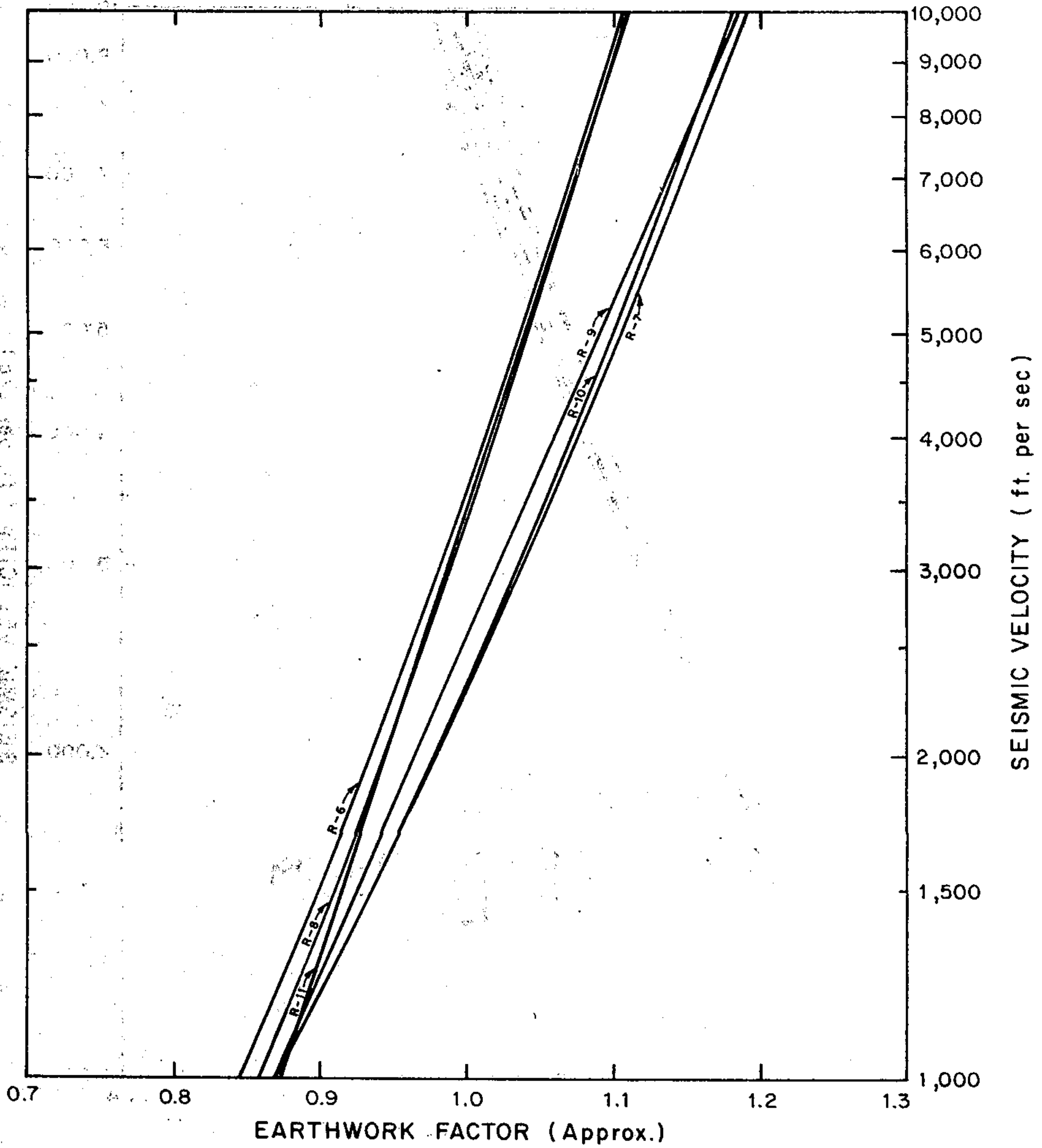


FIGURE 6

RELATIONSHIP BETWEEN SEISMIC VELOCITIES
AND EARTHWORK FACTORS
FOR SOME SEDIMENTARY ROCKS

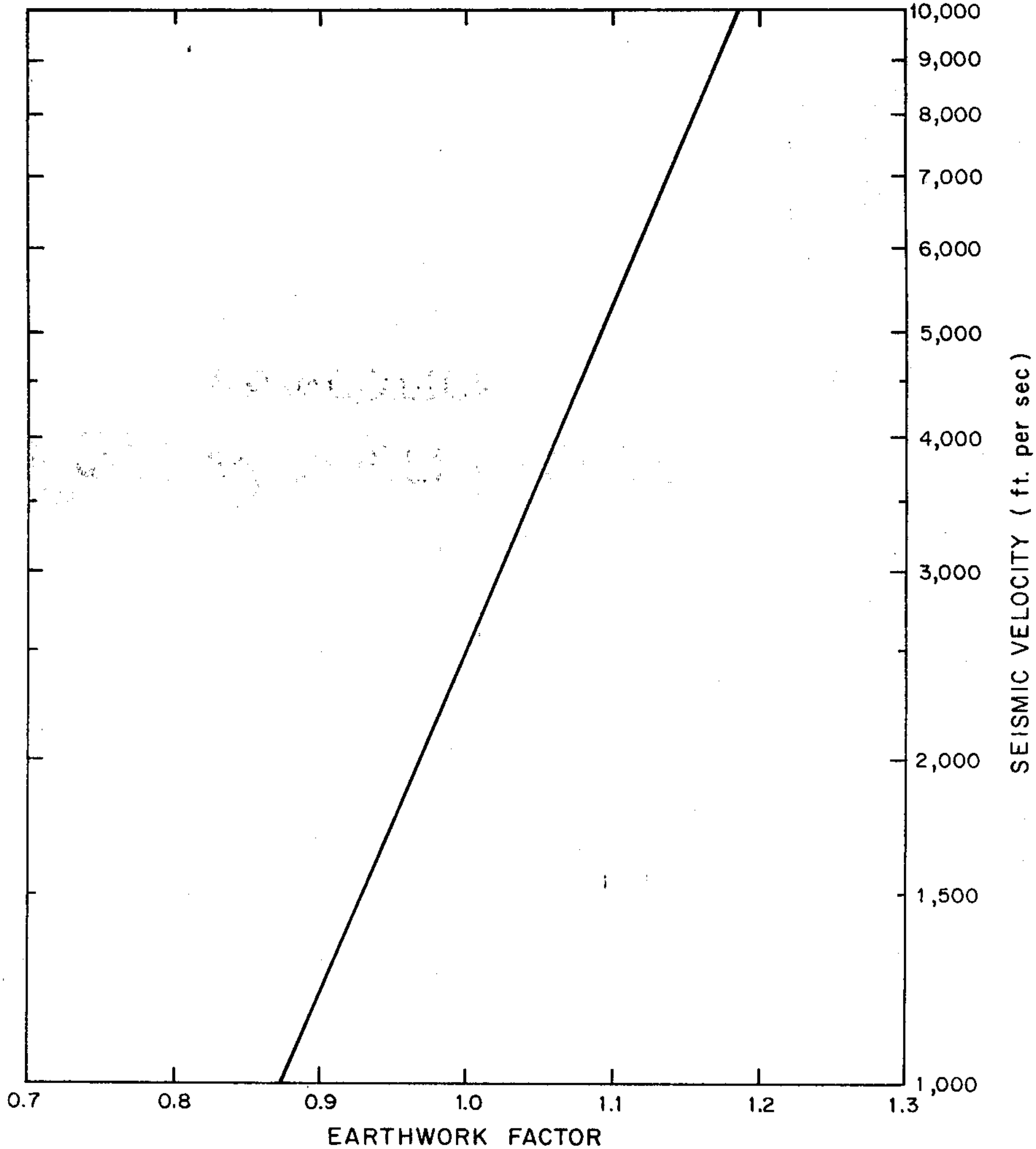


FIGURE 7

TABLE 6

EARTHWORK FACTORS FOR THE SEDIMENTARY PROJECTS AS DETERMINED BY FIELD VOLUMES AND DIFFERENT CURVES.

Projects	Field Factor	EW Factors Original Curve	EW Factors Revised Curve
02-Sha-299	.95	1.02	1.00
04-CC- 4 FR line	1.04	.96	*
CC Line	1.05	1.00	*
6-Fre-198	.95	1.00	.99
07-Ora-91	1.00	1.00	.99

*not included in revision, material does not behave as does the material on the other projects.

TABLE 7

SEDIMENTARY MATERIAL FROM SHASTA COUNTY AND THE EARTH-WORK FACTOR DEVELOPED USING SEDIMENTARY CURVE NO. 11

Velocity (fps)	% Total Volume	Factor from Curve 11	Factor times % Volume
1300	.044580	.91	.040568
1350	.012001	.914	.010969
1450	.005733	.924	.005297
1600	.070561	.939	.066257
1650	.025595	.942	.024111
1800	.088962	.953	.084781
1950	.007769	.965	.007497
2150	.038892	.978	.038036
2300	.102292	.987	.100962
2350	.132971	.99	.131641
2350	.132971	.99	.131641
2650	.003711	1.007	.003737
2700	.040635	1.01	.041041
2950	.014668	1.021	.014976
3050	.078378	1.026	.080416
3400	.058039	1.041	.060419
3700	.160401	1.052	.168742
4000	.066561	1.062	.070688
4600	.048252	1.082	.052209
Total	1.000001		1,0024 or 1.00

Note: Velocity Column feet/sec. (fps) x .305 = Meters/sec (mps)

TABLE 8

SEDIMENTARY MATERIAL FROM FRESNO COUNTY AND THE EARTHWORK FACTOR DEVELOPED USING SEDIMENTARY CURVE NO. 11

Velocity (fps)	% Total Volume	Factor from Curve 11	Factor times % Volume
1200	.380055	.899	.34167
1450	.214685	.924	.198369
4400	.220664	1.077	.237655
5800	.013716	1.116	.015300
6000	.075294	1.119	.084254
6500	.039331	1.129	.044405
8150	.056261	1.158	.065150
	1.000		.9868
			.99

Note: Velocity Column feet/sec. (fps) x .305 = Meters/sec (mps)

TABLE 9

SEDIMENTARY MATERIAL FROM ORANGE COUNTY AND THE EARTH-WORK FACTOR DEVELOPED USING SEDIMENTARY CURVE NO. 11

Velocity (fps)	% Total Volume	Factor from Curve 11	Factor times % Volume
1100	.056690	.888	.050341
1350	.103413	.915	.094623
1400	.051392	.92	.047281
1500	.033198	.93	.030874
1600	.026754	.938	.025095
1700	.008438	.947	.007991
1800	.022084	.953	.021046
1900	.015080	.961	.014492
2000	.189173	.969	.183309
2200	.036255	.981	.035566
2350	.011216	.99	.011104
2500	.015105	.999	.015090
2600	.001663	1.003	.001668
2700	.023135	1.009	.023343
2750	.006576	1.011	.006648
2800	.020344	1.014	.020629
2850	.043905	1.017	.044651
3000	.013149	1.023	.013451
3150	.014159	1.03	.014584
3200	.037813	1.032	.039023
3400	.043615	1.041	.045403
3450	.033652	1.043	.035099
3500	.041188	1.045	.043042
3600	.094890	1.049	.099540
3700	.017061	1.051	.017931
4000	.013478	1.062	.014314
4150	.010568	1.078	.011392
4600	.004978	1.082	.005386
4760	.008387	1.087	.009117
5710	.000642	1.112	.000714
5970	.000374	1.117	.000418
6660	.001627	1.131	.001840
	1.000		.985
			.99

Note: Velocity Column feet/sec (fps) x .305 = Meters/sec (mps)

Development of a Curve for the Contra Costa County Project

The loosely cemented sandstone on this project behaved differently than the sedimentary material on the other projects studied, even though, as can be seen in Table 10, the velocities were very similar. This seems to indicate a different curve is necessary for material which: (a) has high in situ density; (b) crumbles to individual grain size when excavated; and (c) cannot be remolded to its original density.

It was assumed that the higher velocities of this material would behave as any other high velocity sedimentary rock, and would therefore, fall on the straight line formed by the sedimentary curve when plotted on semi log paper. It was further assumed that the lower velocity materials should produce a factor higher than was indicated by the curve for sedimentary materials shown in Figure 7, which was also a straight line on the semi log paper. This produced two parallel straight lines on the semi log graph. A set of curves, shown in Figure 8, was then constructed using several different shapes to effect the crossover between the two parallel lines. The earthwork factors for both portions of the project were calculated using each trial curve. The curve selected was No. 4-7-R, and yields factors of 1.02 and 1.05 for the two portions. The field factors for these portions were 1.04 and 1.05.

The data are insufficient to determine if this curve, shown in Figure 9, is more than an approximation. Additional data will have to be collected and a comparison made between the factors from this curve and the factors from the field to determine if this curve is correct.

This curve should be used for a granular material that degrades to its individual grains when excavated and cannot be remolded to its original overconsolidated state.

Granitic Rock

08-Riv-60-P.M. 2.6/7.2

This project began before this study started, but was observed throughout most of the construction period.

The material was primarily granitic rock with one cut in metamorphic rock. The granitic material ranged from disintegrated granite to fresh quartz diorite or a hard gneiss. The metamorphic material is probably roof pendants, and consists of schists and quartzites.

The total amount of excavation was 1,702,718 cubic yards (1,294,065 m^3). Of this amount, 144,587 cubic yards (109,886 m^3) were used as cement treated base, subbase or export. The balance of this yardage was used as embankment material.

A seismic study had been conducted for design purposes prior to the start of construction. The earthwork factor predicted by the District was 1.10. This was not, however, based on seismic data. The actual earthwork factor obtained in the field was 1.04.

Use of the curve (Figure 10) developed during the original study of 1971(1) to predict an earthwork factor for this project resulted in a prediction of 1.06 indicating that the original granitic curve was applicable to this project also.

It was originally intended to consider the earthwork factors for individual cuts or areas of common degrees of hardness. This proved impractical because of the amount of crosshauling that was done. Most fills are composed of mixtures of material from two or more cuts, and materials from all cuts has been hauled to two or more fills. As a result, it was only possible to calculate an overall earthwork factor for the project. It is possible that crosshauling contributed to a better mixing of hard rock pieces and loose fines, resulting in a lower earthwork factor than would have been obtained otherwise.

TRIAL CURVES 4 THROUGH 7
FOR SEDIMENTARY ROCKS
FOUND ON THE CONTRA COSTA COUNTY PROJECT

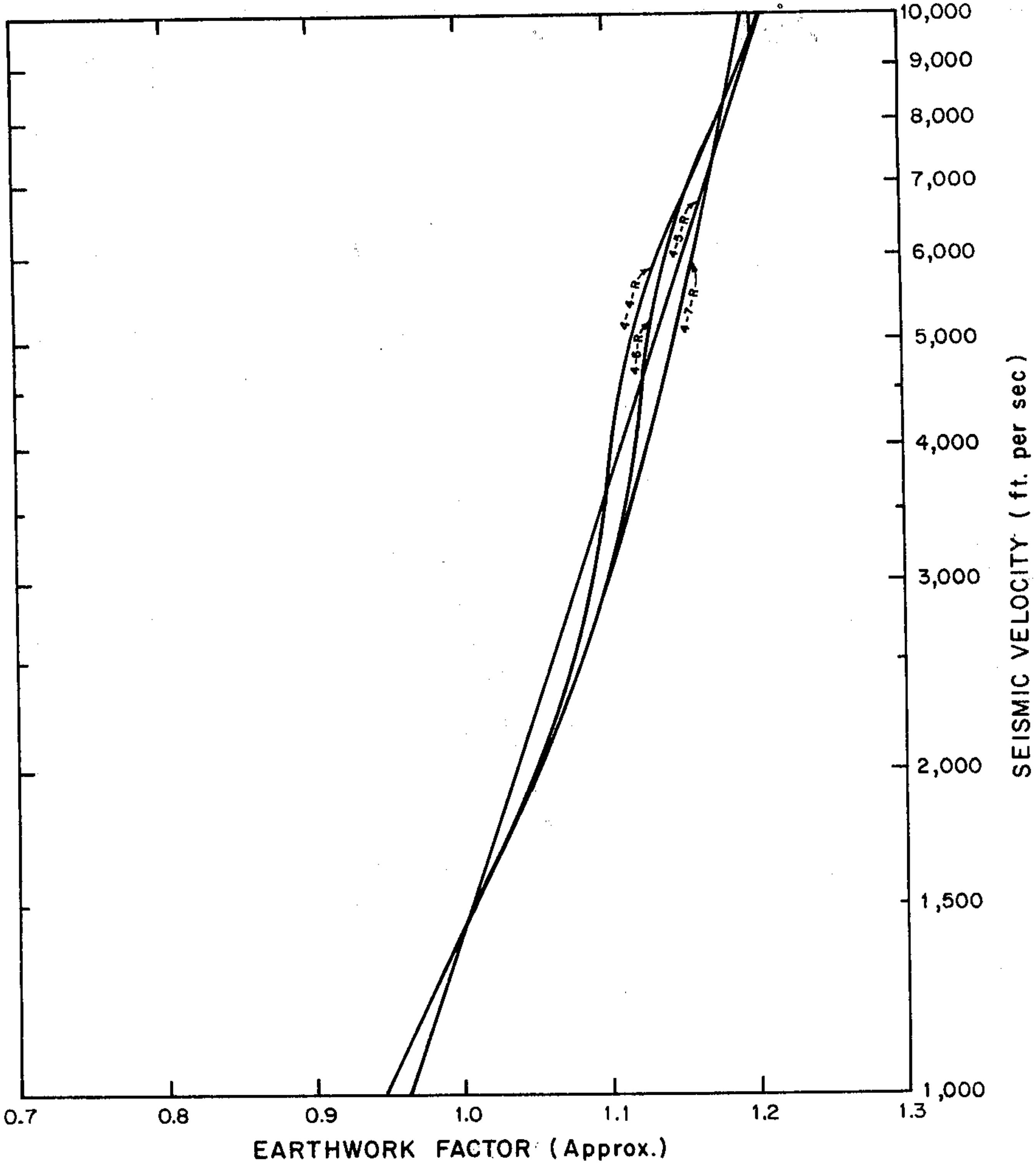


FIGURE 8

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND EARTHWORK FACTORS FOR SANDSTONE FOUND ON THE CONTRA COSTA COUNTY PROJECT

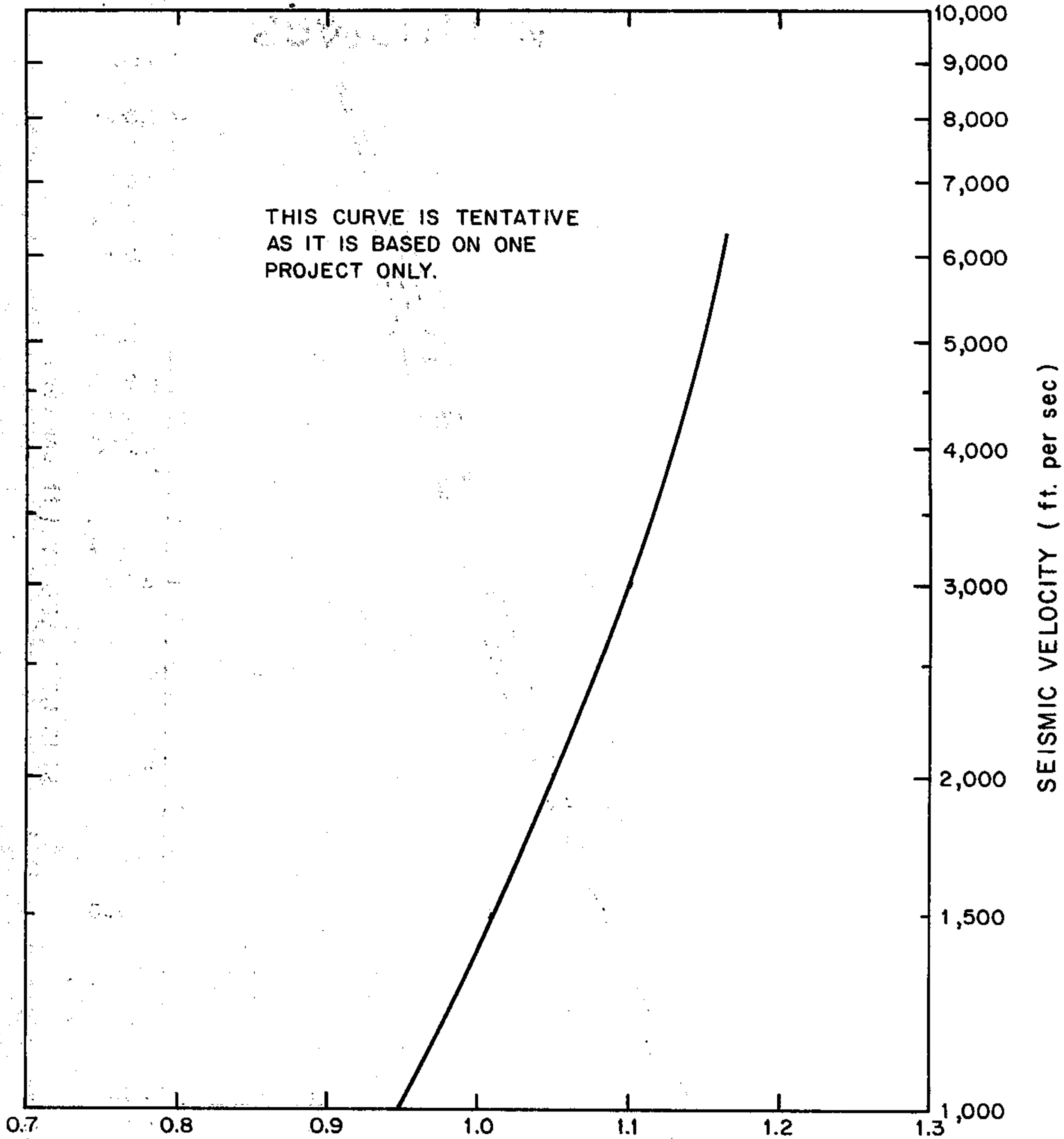


FIGURE 9

TABLE 10

PERCENTAGE OF SEDIMENTARY MATERIAL IN EACH VELOCITY RANGE FROM THE SEDIMENTARY PROJECTS

Velocities (fps)	Projects 07-Ora-91	06-Fre-198	02-Sha-299	04-CC-4
1000-2000	32	59	25	81
2000-2700	25		28	10
2700-3500	28		19	1
3500-4500	14	22	23	2
4500-5000	1		5	
5000-7000		13		6
7000-9000		6		
Totals	100	100	100	100

Note: Velocities Column feet/sec. (fps) x .305 = Meters/sec (mps)

RELATIONSHIP BETWEEN SEISMIC VELOCITIES
AND EARTHWORK FACTORS
FOR GRANITIC ROCK

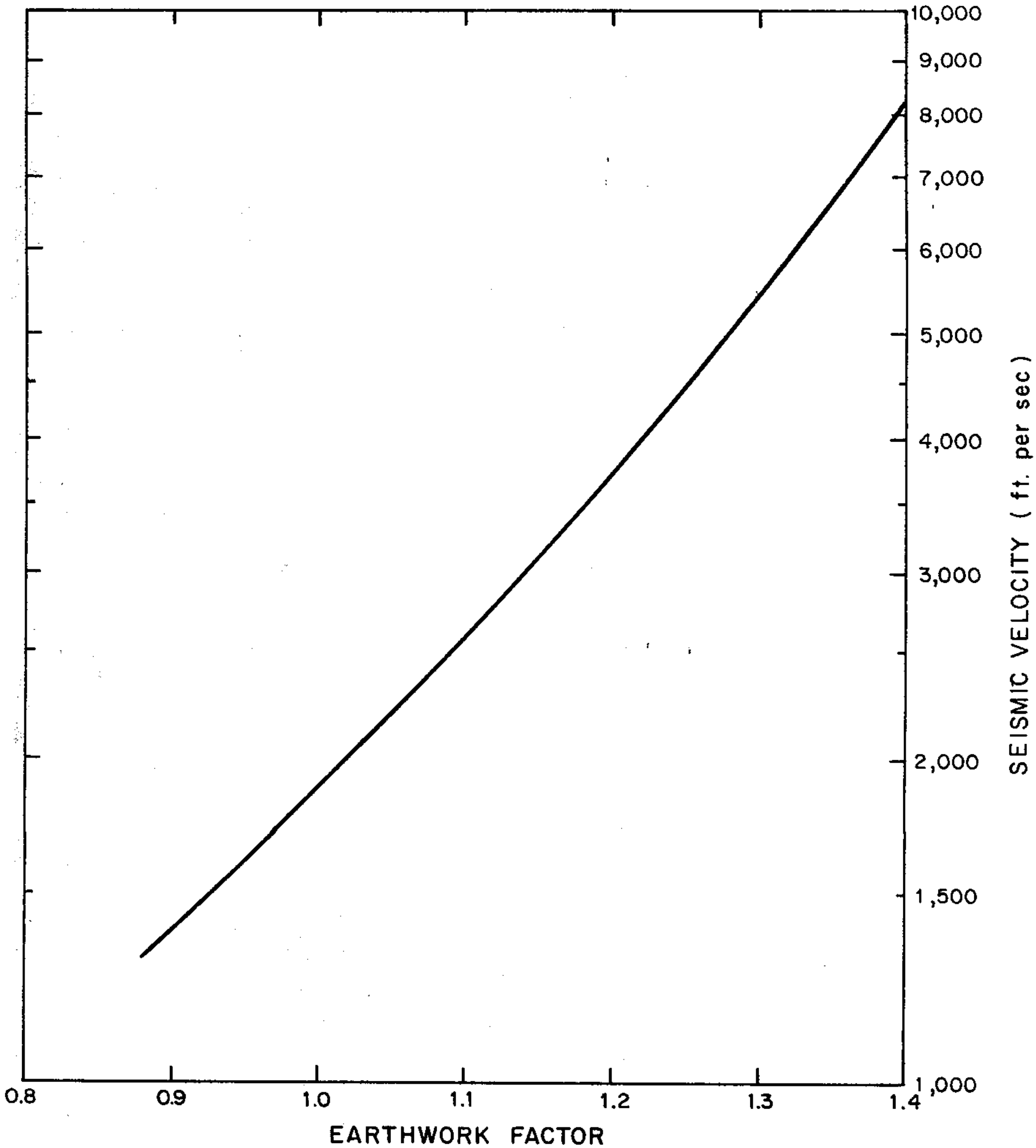


FIGURE 10

REFERENCES

1. Smith, Travis; McCauley, Marvin; Mearns, Ronald; Lister, Bobby; and John, Bennett; June 1971; "Correlation of Seismic Velocities with Earthwork Factors" Interim Report No. 1, California Department of Transportation Research Report No. M&R 632103.

2. Smith, Travis; McCauley, Marvin; Mearns, Ronald; and Baumeister, Karl; January 1972; "Correlation of Seismic Velocities with Earthwork Factors" - Interim Report No. 2, California Department of Transportation Research Report No. M&R 632103.

3. Smith, Travis; McCauley, Marvin; Mearns, Ronald; and Baumeister, Karl; August 1972; "Correlation of Seismic Velocities with Earthwork Factors" - Interim Report No. 3, California Department of Transportation Research Report No. M&R 632103.

4. Smith, Travis; McCauley, Marvin; Mearns, Ronald; and Baumeister, Karl; November 1972; "Correlation of Seismic Velocities with Earthwork Factors" - Final Report, California Department of Transportation Research Report No. M&R 632103.

APPENDIX

Printouts of earthwork factors versus seismic velocities for different materials:

Volcanic pyroclastics
Volcanic flow rocks
Sedimentary Materials
Sandstone on the Contra Costa County project
Granitic rocks

EARTHWORK FACTORS VERSUS SEISMIC VELOCITIES FOR PYROCLASTIC MATERIALS (AS GRAPHED IN FIGURE 4).

SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR
1200	.744	3300	.987	5400	1.096
1250	.754	3350	.991	5450	1.098
1300	.764	3400	.994	5500	1.099
1350	.774	3450	.997	5550	1.101
1400	.783	3500	1.000	5600	1.103
1450	.792	3550	1.003	5650	1.105
1500	.800	3600	1.007	5700	1.107
1550	.809	3650	1.010	5750	1.109
1600	.817	3700	1.013	5800	1.111
1650	.824	3750	1.016	5850	1.113
1700	.832	3800	1.019	5900	1.114
1750	.839	3850	1.022	5950	1.116
1800	.845	3900	1.024	6000	1.118
1850	.852	3950	1.027	6050	1.120
1900	.858	4000	1.030	6100	1.121
1950	.864	4050	1.033	6150	1.123
2000	.870	4100	1.036	6200	1.125
2050	.876	4150	1.038	6250	1.127
2100	.882	4200	1.041	6300	1.128
2150	.887	4250	1.044	6350	1.130
2200	.893	4300	1.046	6400	1.132
2250	.898	4350	1.049	6450	1.133
2300	.903	4400	1.051	6500	1.135
2350	.908	4450	1.054	6550	1.136
2400	.913	4500	1.056	6600	1.138
2450	.918	4550	1.059	6650	1.140
2500	.923	4600	1.061	6700	1.141
2550	.928	4650	1.064	6750	1.143
2600	.932	4700	1.066	6800	1.144
2650	.937	4750	1.068	6850	1.146
2700	.941	4800	1.070	6900	1.147
2750	.945	4850	1.073	6950	1.149
2800	.950	4900	1.075	7000	1.150
2850	.954	4950	1.077	7050	1.152
2900	.958	5000	1.079	7100	1.153
2950	.962	5050	1.081	7150	1.155
3000	.966	5100	1.083	7200	1.156
3050	.970	5150	1.085	7250	1.158
3100	.973	5200	1.088	7300	1.159
3150	.977	5250	1.090	7350	1.161
3200	.980	5300	1.092	7400	1.162
3250	.984	5350	1.094	0	.000

EARTHWORK FACTORS VERSUS SEISMIC VELOCITIES FOR VOLCANIC FLOW ROCKS (AS GRAPHED IN FIGURE 4).

SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR
1150	.792	3400	1.060	5650	1.169
1200	.803	3450	1.064	5700	1.170
1250	.814	3500	1.067	5750	1.172
1300	.824	3550	1.070	5800	1.173
1350	.834	3600	1.073	5850	1.175
1400	.844	3650	1.076	5900	1.176
1450	.853	3700	1.079	5950	1.178
1500	.862	3750	1.082	6000	1.179
1550	.871	3800	1.085	6050	1.181
1600	.879	3850	1.088	6100	1.182
1650	.887	3900	1.091	6150	1.183
1700	.895	3950	1.094	6200	1.185
1750	.903	4000	1.097	6250	1.186
1800	.910	4050	1.099	6300	1.188
1850	.917	4100	1.102	6350	1.189
1900	.923	4150	1.105	6400	1.190
1950	.930	4200	1.107	6450	1.192
2000	.936	4250	1.110	6500	1.193
2050	.942	4300	1.113	6550	1.195
2100	.948	4350	1.115	6600	1.196
2150	.954	4400	1.118	6650	1.197
2200	.959	4450	1.120	6700	1.199
2250	.965	4500	1.123	6750	1.200
2300	.970	4550	1.125	6800	1.201
2350	.975	4600	1.128	6850	1.202
2400	.980	4650	1.130	6900	1.204
2450	.985	4700	1.132	6950	1.205
2500	.990	4750	1.134	7000	1.206
2550	.995	4800	1.136	7050	1.208
2600	.999	4850	1.138	7100	1.209
2650	1.004	4900	1.140	7150	1.210
2700	1.008	4950	1.142	7200	1.211
2750	1.012	5000	1.144	7250	1.212
2800	1.016	5050	1.146	7300	1.213
2850	1.020	5100	1.148	7350	1.214
2900	1.024	5150	1.150	7400	1.215
2950	1.028	5200	1.152	7450	1.216
3000	1.032	5250	1.154	7500	1.217
3050	1.036	5300	1.156	7550	1.218
3100	1.040	5350	1.158	7600	1.219
3150	1.043	5400	1.160	7650	1.220
3200	1.047	5450	1.162	7700	1.221
3250	1.050	5500	1.163	7750	1.221
3300	1.054	5550	1.165	7800	1.222
3350	1.057	5600	1.167	7850	1.223

VOLCANIC FLOW ROCKS

SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR
7900	1.224	8600	1.235	9300	1.245
7950	1.225	8650	1.236	9350	1.245
8000	1.226	8700	1.237	9400	1.246
8050	1.227	8750	1.237	9450	1.246
8100	1.228	8800	1.238	9500	1.247
8150	1.229	8850	1.239	9550	1.247
8200	1.229	8900	1.239	9600	1.248
8250	1.230	8950	1.240	9650	1.248
8300	1.231	9000	1.241	9700	1.249
8350	1.232	9050	1.241	9750	1.249
8400	1.233	9100	1.242	9800	1.250
8450	1.233	9150	1.243	9850	1.250
8500	1.234	9200	1.243	9900	1.251
8550	1.235	9250	1.244	9950	1.251

EARTHWORK FACTORS VERSUS SEISMIC VELOCITIES FOR SEDIMENTARY MATERIALS (AS GRAPHED IN FIGURE 7).

SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR
1000	.873	3250	1.034	5500	1.106
1050	.880	3300	1.036	5550	1.107
1100	.886	3350	1.038	5600	1.108
1150	.892	3400	1.040	5650	1.110
1200	.898	3450	1.042	5700	1.111
1250	.904	3500	1.044	5750	1.112
1300	.909	3550	1.046	5800	1.113
1350	.914	3600	1.048	5850	1.114
1400	.919	3650	1.050	5900	1.115
1450	.924	3700	1.052	5950	1.117
1500	.929	3750	1.054	6000	1.118
1550	.933	3800	1.056	6050	1.119
1600	.938	3850	1.057	6100	1.120
1650	.942	3900	1.059	6150	1.121
1700	.946	3950	1.061	6200	1.122
1750	.950	4000	1.063	6250	1.123
1800	.954	4050	1.064	6300	1.124
1850	.957	4100	1.066	6350	1.125
1900	.961	4150	1.068	6400	1.126
1950	.965	4200	1.069	6450	1.127
2000	.968	4250	1.071	6500	1.128
2050	.971	4300	1.073	6550	1.129
2100	.975	4350	1.074	6600	1.130
2150	.978	4400	1.076	6650	1.131
2200	.981	4450	1.077	6700	1.132
2250	.984	4500	1.079	6750	1.133
2300	.987	4550	1.080	6800	1.134
2350	.990	4600	1.082	6850	1.135
2400	.993	4650	1.083	6900	1.136
2450	.995	4700	1.085	6950	1.137
2500	.998	4750	1.086	7000	1.138
2550	1.001	4800	1.088	7050	1.139
2600	1.003	4850	1.089	7100	1.140
2650	1.006	4900	1.090	7150	1.141
2700	1.009	4950	1.092	7200	1.142
2750	1.011	5000	1.093	7250	1.143
2800	1.013	5050	1.094	7300	1.144
2850	1.016	5100	1.096	7350	1.145
2900	1.018	5150	1.097	7400	1.146
2950	1.021	5200	1.098	7450	1.147
3000	1.023	5250	1.100	7500	1.148
3050	1.025	5300	1.101	7550	1.149
3100	1.028	5350	1.102	7600	1.150
3150	1.030	5400	1.104	7650	1.151
3200	1.032	5450	1.105	7700	1.152

SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR
7750	1.152				
7800	1.153				
7850	1.154				
7900	1.155				
7950	1.156				

EARTHWORK FACTORS VERSUS SEISMIC VELOCITIES FOR CONTRA COSTA COUNTY SANDSTONE (AS GRAPHED IN FIGURE 9).

SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR
1000	.947	2750	1.089	4500	1.139
1050	.954	2800	1.091	4550	1.140
1100	.961	2850	1.094	4600	1.141
1150	.968	2900	1.096	4650	1.141
1200	.974	2950	1.098	4700	1.142
1250	.980	3000	1.100	4750	1.143
1300	.986	3050	1.102	4800	1.144
1350	.992	3100	1.103	4850	1.144
1400	.997	3150	1.105	4900	1.145
1450	1.002	3200	1.106	4950	1.146
1500	1.007	3250	1.108	5000	1.147
1550	1.012	3300	1.109	5050	1.147
1600	1.017	3350	1.111	5100	1.148
1650	1.021	3400	1.112	5150	1.149
1700	1.026	3450	1.113	5200	1.149
1750	1.030	3500	1.115	5250	1.150
1800	1.034	3550	1.116	5300	1.151
1850	1.038	3600	1.118	5350	1.152
1900	1.042	3650	1.119	5400	1.152
1950	1.046	3700	1.120	5450	1.153
2000	1.050	3750	1.121	5500	1.154
2050	1.053	3800	1.123	5550	1.154
2100	1.056	3850	1.124	5600	1.155
2150	1.059	3900	1.125	5650	1.155
2200	1.062	3950	1.126	5700	1.156
2250	1.065	4000	1.128	5750	1.157
2300	1.067	4050	1.129	5800	1.157
2350	1.070	4100	1.130	5850	1.158
2400	1.072	4150	1.131	5900	1.159
2450	1.075	4200	1.132	5950	1.159
2500	1.078	4250	1.134	6000	1.160
2550	1.080	4300	1.135	6050	1.160
2600	1.082	4350	1.136	6100	1.161
2650	1.085	4400	1.137	6150	1.161
2700	1.087	4450	1.138	6200	1.162

EARTHWORK FACTORS VERSUS SEISMIC VELOCITIES FOR GRANITE ROCKS (AS GRAPHED IN FIGURE10).

SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR	SEISMIC VEL.	FACTOR
1400	.910	3650	1.194	5900	1.318
1450	.921	3700	1.197	5950	1.320
1500	.932	3750	1.201	6000	1.322
1550	.942	3800	1.204	6050	1.324
1600	.952	3850	1.208	6100	1.326
1650	.962	3900	1.211	6150	1.328
1700	.971	3950	1.215	6200	1.330
1750	.980	4000	1.218	6250	1.332
1800	.989	4050	1.221	6300	1.334
1850	.998	4100	1.224	6350	1.336
1900	1.006	4150	1.228	6400	1.338
1950	1.014	4200	1.231	6450	1.340
2000	1.021	4250	1.234	6500	1.341
2050	1.029	4300	1.237	6550	1.343
2100	1.036	4350	1.240	6600	1.345
2150	1.043	4400	1.243	6650	1.347
2200	1.050	4450	1.246	6700	1.349
2250	1.057	4500	1.249	6750	1.351
2300	1.063	4550	1.252	6800	1.352
2350	1.070	4600	1.255	6850	1.354
2400	1.076	4650	1.258	6900	1.356
2450	1.082	4700	1.260	6950	1.358
2500	1.088	4750	1.263	7000	1.360
2550	1.094	4800	1.266	7050	1.361
2600	1.100	4850	1.269	7100	1.363
2650	1.105	4900	1.271	7150	1.365
2700	1.110	4950	1.274	7200	1.366
2750	1.116	5000	1.277	7250	1.368
2800	1.120	5050	1.279	7300	1.370
2850	1.125	5100	1.282	7350	1.372
2900	1.130	5150	1.285	7400	1.373
2950	1.135	5200	1.287	7450	1.375
3000	1.140	5250	1.290	7500	1.377
3050	1.144	5300	1.292	7550	1.378
3100	1.149	5350	1.295	7600	1.380
3150	1.153	5400	1.297	7650	1.381
3200	1.157	5450	1.299	7700	1.383
3250	1.162	5500	1.301	7750	1.384
3300	1.166	5550	1.304	7800	1.385
3350	1.170	5600	1.306	7850	1.387
3400	1.174	5650	1.308	7900	1.388
3450	1.178	5700	1.310	7950	1.389
3500	1.182	5750	1.312	8000	1.390
3550	1.186	5800	1.314		
3600	1.190	5850	1.316		